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Maximum acceptable weight of lift reflects peak lumbosacral extension moments in a functional capacity evaluation test using free style, stoop and squat lifting

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It is unclear whether the maximum acceptable weight of lift (MAWL), a common psychophysical method, reflects joint kinetics when different lifting techniques are employed. In a within-participants study ($n = 12$), participants performed three lifting techniques – free style, stoop and squat lifting from knee to waist level – using the same dynamic functional capacity evaluation lifting test to assess MAWL and to calculate low back and knee kinetics. We assessed which knee and back kinetic parameters increased with the load mass lifted, and whether the magnitudes of the kinetic parameters were consistent across techniques when lifting MAWL. MAWL was significantly different between techniques ($p = 0.03$). The peak lumbosacral extension moment met both criteria: it had the highest association with the load masses lifted ($r > 0.9$) and was most consistent between the three techniques when lifting MAWL (ICC = 0.87). In conclusion, MAWL reflects the lumbosacral extension moment across free style, stoop and squat lifting in healthy young males, but the relation between the load mass lifted and lumbosacral extension moment is different between techniques.

Practitioner Summary: Tests of maximum acceptable weight of lift (MAWL) from knee to waist height are used to assess work capacity of individuals with low-back disorders. This article shows that the MAWL reflects the lumbosacral extension moment across free style, stoop and squat lifting in healthy young males, but the relation between the load mass lifted and lumbosacral extension moment is different between techniques. This suggests that standardisation of lifting technique used in tests of the MAWL would be indicated if the aim is to assess the capacity of the low back.

Keywords: biomechanics; physical work capacity; manual handling; low-back pain

1. Introduction

Worldwide, 37% of low-back pain (LBP) is attributed to occupation (Punnett *et al*. 2005). Its incidence has consistently been shown to be associated with work that involves high mechanical loads on the low back such as in trunk bending and lifting (Marras *et al*. 1995, Norman *et al*. 1998, Lötters *et al*. 2003, Lis *et al*. 2007). Moreover, work-related LBP was estimated to cause 818,000 disability-adjusted life years lost annually across the world (Punnett *et al*. 2005).

Hamberg-van Reenen *et al*. (2006) showed that a relatively low physical capacity, in terms of endurance of the low back muscles, and flexion and rotation ranges of motion of the spine in combination with relatively high work demands resulted in an increased risk of LBP. In addition, to prevent recurrence of LBP, it may therefore be useful to assess the physical capacity of workers about to resume work after a period of LBP (Payne and Harvey 2010). To this end, tests of maximum acceptable weight of lift (MAWL) are commonly used (Gouttebarge *et al*. 2009). Supporting this approach, in the study of Hamberg-van Reenen (2006) a low MAWL was found to be predictive of future LBP and Kuijer *et al*. (2011) reported higher MAWL to be predictive of work participation in patients with LBP. The underlying assumption of using the MAWL in the context of LBP appears to be that it reflects the capacity of the low back. This is supported by the suggestion of Nussbaum and Lang (2005) that relative joint demands may determine MAWL and the relation found between back muscle activity levels and decisions to modify weights during tests of MAWL (Jorgensen *et al*. 1999, Davis *et al*. 2000). On the other hand, Schenk *et al*. (2006) found that only 18–19% of the variance in MAWL, assessed using a functional capacity evaluating (FCE) lifting test, could be accounted for by basic capacities such as strength and endurance of the trunk muscles. Although trunk capacity partially explained MAWL, several uncertainties remain, including the effect of differences in lifting technique.

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In the literature, three lifting techniques are often mentioned, namely squat, stoop and free style lifting (van Dieën *et al*. 1999, Burgess-Limerick 2003). The starting position of squat lifting is characterised by flexed knees and a relatively straight trunk. Stoop lifting is characterised by a starting position with extended knees, and a flexed trunk (Burgess-Limerick 2003). In practice, often a third lifting technique intermediate to stoop and squat lifting is used. Burgess-Limerick (2003) reported that when people were free to select a lifting technique, they used a semi-squat lift, in which both knees and the trunk are flexed. This technique is often referred to as free style lifting, which results in the highest load mass lifted according to a review by Straker (2003).

Due to the differences in kinematics of these three lifting techniques, it is questionable whether the MAWL reflects the same joint kinetics across these techniques. For example, Trafimow *et al*. (1993) and Hagen *et al*. (1995) found indications that strength and endurance of the M. Quadriceps limits lifting performance in squat lifting, suggesting that the MAWL determined with this technique would reflect the knee extension moment or work the subject is able or willing to produce. On the other hand, in stoop lifting, flexor moments dominate knee kinetics (Toussaint *et al*. 1992). Hence, it seems unlikely that the MAWL determined in stoop lifting reflects the same underlying capacity.

This study, therefore, aimed to answer the following question: Does the MAWL reflect back or knee kinetics and does it do so consistently across free style, stoop and squat lifting tests? To answer this question, we correlated kinetic parameters at the low back and knees to the load mass lifted during performance of a dynamic functional capacity evaluation lifting test using the three lifting techniques. Furthermore, we determined the consistency of the magnitude of the joint kinetics obtained when lifting the MAWL across lifting techniques.

2. Methods

2.1. *Participants*

Twelve healthy males with no history of low-back pain or trauma leading to impairments in the last six months participated. Only male participants were included, because the anthropometric models used for inverse dynamical analysis do predict actual male anthropometry better than female anthropometry (Kingma *et al*. 1996b). No history of back pain was confirmed by a telephone interview prior to the experiment. The participants' mean age was 23 years (range 21–31 years), their mean height was 182 cm (range 170–197 cm) and their mean body mass was 76 kg (range 62–100 kg). All participants gave informed consent prior to the study. Moreover, they were informed that they could be asked to lift more than 25 kg and they were allowed to cease participating at any time. The study has been approved by the local Ethics Committee.

2.2. *Maximum acceptable weight of lift (MAWL)*

A within-participants design was used to test whether MAWL in a free style, stoop and squat lifting test is limited by the same kinetic parameter at the same joint. For each lifting technique, the MAWL was determined using the dynamic lower lifting endurance (LLE) test of the Ergo-Kit® FCE (Ergo Control, Enschede, the Netherlands). The LLE test is designed to determine the maximum safe load mass that an individual can lift frequently during an 8-h work day. Gouttebarge *et al*. (2005, 2006) showed that this test is reliable both in participants with and without musculoskeletal disorders. The test does not prescribe a specific lifting technique. For this study, each participant started with free style lifting and then, alternating between participants, squat and stoop lifting. This sequence was used so that the instructions given for squat or stoop lifting did not affect free style lifting. The lifting technique for stoop and squat lifting was demonstrated by the test leader prior to the trials in which stoop and squat lifting was performed. The participants attempted to perform the required technique and were given feedback by the test leader until the lifting technique was performed correctly. In addition, for the free style lifting technique the participant practiced but no feedback on technique was given. During one day, each participant performed all three lifting techniques. After each session with a lifting technique, participants had a break of at least 15 min to recover. In all other respects, the procedure followed the protocol of the LLE test (Ergo Control 2002). All tests were carried out by the same certified test leader.

The LLE test consists of lifting a box from a shelf at hip height in front of the participant to a step (height 20 cm above the ground) to the left, and back to the shelf. The load mass has to be handled horizontally with two hands on the handles. The LLE test has a total duration of at least 10 min, but no more than 15 min. The initial load mass was 5 kg (2.5 kg for the box and 2.5 kg for the weight). The test leader monitored the time from the onset of the performance of the lifts and made sure the participant maintained the same lifting technique during the tests with squat and stoop techniques. The participants performed four lifts during each minute of the test, with a new lifting movement starting at 0, 10, 20 and 30 s, with each lift lasting approximately 1 s within this window of 10 s. In the last 20 s of each minute, the person was standing erect and had time to recover. During that time, the heart rate was read from a Polar (Vantage NV) wrist receiver. In addition, a rating of perceived discomfort (RPD) and a rating of perceived heaviness (RPH) of the load mass were determined, both on a 10-point Borg rating scale (0: not at all, 10: very, very hard). The scales including the verbal anchors were visible for the participants. For the LLE test, an age-dependent maximal heart rate (MHR) was defined. The MHR was calculated as $(220 - \text{age}) \times 0.85$ (Ergo Control 2002).

The load mass was increased, held constant or decreased depending on the results of the MHR, RPD or RPH and whether the lifting tests were performed in an uncoordinated manner. An uncoordinated manner was defined as (Ergo Control 2002): the box is not lifted but shoved over the shelf and drops a few centimetres before the box is lifted, or the participant loses balance when lifting or lowering the box, or the box is dropped on the shelf or step with a thud, or the required lowering and lifting of the box cannot be performed within 10 s. After each set of four lifts, the load mass was increased or decreased by 2.5 kg or 5 kg within the first 10 min and after 10 min by 2.5 kg. The load mass was increased when the lift was performed in a coordinated manner, with the RPD and RPH ≤ 3, and the heart rate $\leq$ MHR. The load mass was decreased when the lift was performed in an uncoordinated manner, or RPD or RPH ≥ 5, or the heart rate $>$ MHR. The load mass was held constant when the lift was performed in a coordinated manner, and RPD or RPH $= 4$, and the heart rate $\leq$ MHR. Participants were considered to reach their MAWL upon:

- lifting the same load mass for 3 min after 10 min or in the 10th min.
- request by the participant to end the test because the load mass was too heavy to lift.
- completing 15 sets of four lifts.

The LLE test was ended when one of these criteria was met. In this study, only the first and third criterion applied and none of the participants requested ending the test because the load mass was judged to be too heavy. If the first criterion applied, the MAWL was defined as the load mass the participant lifted in the last three sets of four lifts. For the other criteria, the MAWL was defined as the heaviest load mass lifted in a set of four lifts, during which the RPD and RPH < 5.

2.3. Low back and knee kinetics

To calculate the kinetics at the low back and knees, the following procedure was used. Kinematic data of the lifting techniques were collected using a 3D-movement registration system (Optotrak, Waterloo ON Canada) at 100 samples/s. The positions of four LED markers on braces attached to the calves, thighs and pelvis were recorded. Prior to the actual experiment, the positions of bony landmarks were recorded and related to the position of the braces by means of a pointer (Cappozzo *et al.* 1995). Ground reaction forces were recorded using two force plates (Kistler, type 9281 B11). These data were first filtered using a low pass filter at 30 Hz before being stored at 100 samples/s. The synchronisation of the kinematic data and force data was achieved by means of electrical pulses.

Matlab was used to analyse Optotrak-data and force plate-data. The marker positions were filtered using a fourth-order Butterworth filter using a cut-off frequency of 5 Hz. Net reaction forces and moments at each joint were calculated in a local, caudal reference frame using an inverse dynamic 3D model consisting of seven segments (the feet, lower legs, upper legs and pelvis; Kingma *et al.* 1996a) using ground reaction forces, kinematic data and anthropometric data of the participants. Angular velocities and internal moments in the extension direction were denoted positive. Joint power was calculated as the product of moments and angular velocities and integration yielded joint work. Peak flexion and extension moments as well as total work were determined at each joint for all lifts. Mean values were calculated for each subject per load mass and lifting technique. These mean values were used for further analyses. For all joints, high correlations were found between total work and peak power ($r = 0.80$–0.97). Therefore, peak power was not used in subsequent analyses.

The three lifting techniques mainly differ in the kinematics of the low back and of the knees; moreover, parameters for back and hip kinetics were highly correlated. In the LLE test, the load mass is lifted from a shelf at hip height to a step to the left, and back to the shelf. Consequently, the loading of the left knee was higher than that of the right knee. Therefore, the following joint kinetic parameters were included in the analysis: peak extension moment at the lumbosacral (L5S1) joint (MexL5S1), peak lateroflexion L5S1 moment (MlfL5S1), peak rotation L5S1 moment (MrL5S1), total work performed during L5S1 extension (WexL5S1), and peak flexion moment around the left knee (Mflknee), peak extension moment around the left knee

(Mexlknee), total work performed during flexion of the left knee (Wflknee) and total work performed during extension of the left knee (Wexlknee).

2.4. *Statistical analysis*

Differences in MAWL between the three lifting techniques were non-parametrically tested using Friedman's test and subsequently followed by a pair wise comparison using Wilcoxon matched pairs tests.

If the MAWL reflects a certain kinetic parameter at the knee or back during lifting, then the load mass lifted during the LLE test must correlate with that joint kinetic parameter. To determine which kinetic parameters are correlated with load mass lifted, the Spearman correlation coefficients (r) between the load mass lifted during the LLE tests and each low back and knee kinetic parameter was calculated for each individual and each lifting technique. The absolute median of the Spearman correlation coefficient (r) was used to assess the strength of the relationship between these load masses lifted during the LLE test for the three lifting techniques and the low back and knee kinetics. An $r < 0.50$ was qualified as poor, $0.50 \leq r < 0.80$ as moderate and $r \geq 0.80$ as good (Altman 1991, Innes and Straker 1999, Gouttebarge *et al*. 2004).

If the MAWL reflects a certain low back or knee kinetic parameter across lifting techniques, not only should there be a high correlation between the load mass and this kinetic parameter within each technique, but also the magnitude of this kinetic parameter should be the same across techniques when lifting the MAWL. Therefore, an intraclass correlation coefficient (ICC) (type 2.1), including a 95% confidence interval (95% CI) was calculated. An $\text{ICC} < 0.60$ was qualified as poor, $0.60 \leq \text{ICC} < 0.80$ as moderate and $\text{ICC} \geq 0.80$ as good (Portney and Watkins 1993, Innes and Straker 1999, Gouttebarge *et al*. 2006). For all tests, a probability level (p-value) of 0.05 was considered statistically significant.

3. Results

3.1. *Maximum acceptable weight of lift (MAWL)*

As expected, free style lifting resulted in the highest MAWL (mean = 16.5 kg, SD = 4.7) compared to stoop (mean = 15.4 kg, SD = 6.2) and squat lifting (mean = 13.5 kg, SD = 6.1) ($p = 0.03$). Pairwise comparisons showed that the free style lifting differed from squat lifting ($p = 0.04$). No differences were found between free style lifting and stoop lifting ($p = 0.19$) and stoop and squat lifting ($p = 0.15$). No order effects were found for stoop and squat lifts (Mann–Whitney tests $p > 0.82$).

3.2. *Association between load mass and low back and knee kinetics*

For all three lifting techniques, the correlation between the load mass lifted and MexL5S1 had the highest values. Moreover, the median r for all three lifting techniques was ≥ 0.80: a good correlation (Table 1). The overall median r of MlfL5S1, MrL5S1, Mflknee, Mexlknee and Wflknee was moderate. WexL5S1 and Wexlknee had a poor correlation: $r < 0.50$.

3.3. *Consistency of low back and knee kinetics when lifting the MAWL*

The mean ICC showed that MexL5S1 was fairly constant across lifting techniques at the MAWL for each technique (Table 2). The same was true for MlflL5S1. Both ICCs were $\geq$0.80. The other joint kinetic parameters showed poor agreement: $\text{ICC} < 0.60$.

Table 1. The median across participants of the Spearman correlation (r) between the biomechanical parameters MexL5S1, MlfL5S1, MrL5S1, WexL5S1, Mflknee, Mexlknee, Wflknee, Wexlknee and the load masses lifted for the three lifting techniques 'free style', 'stoop' and 'squat' and the overall median ($n = 10$).

r	MexL5S1	MlfL5S1	MrL5S1	WexL5S1	Mflknee	Mexlknee	Wflknee	Wexlknee
Free style	0.97	0.62	0.70	0.35	0.46	0.52	0.52	0.28
Stoop	0.98	0.56	0.79	0.53	0.60	0.50	0.50	0.27
Squat*	0.95	0.47	0.81	0.38	0.54	0.41	0.65	0.27
Overall	0.97	0.59	0.78	0.44	0.57	0.51	0.51	0.31

Note: *$n = 9$, due to non-visible markers.

Table 2. The Intraclass Correlation Coefficient (ICC) (95% confidence interval) between the biomechanical parameters MexL5S1, MlfL5S1, MrL5S1, WexL5S1, Mflknee, Mexlknee, Wflknee, Wexlknee for the three lifting techniques given the highest MAWL ($n = 9$).

	MexL5S1	MlfL5S1	MrL5S1	WexL5S1	Mflknee	Mexlknee	Wflknee	Wexlknee
ICC	0.87	0.80	0.58	0.14	0.24	0.24	−0.02	0.21
95%CI	0.67–0.97	0.52–0.95	0.18–0.87	−0.21–0.63	−0.14–0.70	−0.15–0.70	−0.31–0.48	−0.16–0.68

4. Discussion

The MAWL reflects the peak lumbosacral extension moment across free style, stoop and squat lifting between knee and waist level. However, the MAWL systematically differed between lifting techniques, while the peak lumbosacral extension moment when lifting the MAWL was consistent across techniques.

4.1. Strengths and weaknesses

As expected, free style lifting resulted in the highest MAWL compared to stoop and squat lifting (Straker 2003). However, in this study we did not use a randomised design. To prevent any effect of instruction of stoop and squat lifting on free style lifting, free style lifting was always performed first in this study. Therefore, fatigue might have influenced this result. The test trial for each of the three lifting techniques lasted a maximum of 15 min. The goal of the lifting test was to establish the load mass that corresponds to a four ('somewhat hard') on a 10-point scale for RPH or RPD (0: not at all, 10: very, very hard). Each minute, four lifts were performed, each after 10 s, with each lifting lasting about 1 s. So, during the four 10 s lifting periods and the last 20 s of each minute the participant could recover. After 15 min, the participants rested for 15 min and they were asked whether they felt recovered and no more fatigued before the second trial was started. None of the participants said that they needed extra time to recover. Van Dieën *et al.* (2001) showed that for 360 lifts in 1 h of a 45-L crate, weighted with a stable 10–kg mass no fatigue-related changes could be demonstrated for lumbar moments. In addition, the values for MAWL in the present study were fairly comparable to those in other studies. For example, in free style lifting, a mean of 16.5 $\pm$ 4.7 kg was found, for which Straker and Cain (1999) reported MAWL of 12.0 $\pm$ 5.2 kg and Zhu and Zhang (1990) reported MAWL of 15.6 $\pm$ 2.0 kg. In these studies, similar to the present study, four lifts were performed each minute, but the order of lifting techniques was randomly assigned. Therefore, fatigue probably did not have a confounding effect. Moreover, these randomised studies of Zhu and Zhang (1990) and Straker and Cain (1999) also found similar effects of lifting technique on MAWL. Given the converging evidence obtained with these divergent designs, we believe that order effects have not played a role.

In this study, an FCE lifting test between knee and waist level was used to determine the MAWL. Uncoordinated lifting could also have affected MAWL according to the LLE test criteria. However, this did not occur during the trials, and therefore this criterion has not influenced our results. The same holds true for the heart rate criterion. In our healthy male participants, ratings of perceived discomfort did not affect MAWL. Thus MAWL was based on the rating of perceived heaviness of the participants and the corresponding test criteria.

4.2. Low back versus knee kinetics

Free style, stoop and squat lifting between about knee and waist level were used to assess which joint kinetic is reflected by the MAWL. These three techniques differ mainly in trunk and knee movements. Based on the results of former studies (Toussaint *et al.* 1992, Trafimow *et al.* 1993, Hagen *et al.* 1995, Gagnon *et al.* 1996, Gagnon 1997), it could be expected that a different joint kinetic might be reflected by the MAWL for each lifting technique. However, this appeared not to be the case. Only MexL5S1, the peak lumbosacral extension moment, was closely correlated with load mass and it was so for all three techniques. In addition, within participants, MexL5S1 had similar values across the three techniques when lifting the MAWL. This may suggest that the peak lumbosacral extension moment limits lifting capacity in all three techniques. However, the lifting techniques coincide with different trunk postures and thereby different locations of the extensor muscles on their length – tension relation and different muscle moment arms. This could suggest differences in moment producing capacities between the three techniques. Based on the data of Raschke and Chaffin (1999) on the relation between lumbar angle and extensor strength and of Gill *et al.* (2007) on the differences in lumbar angles between lifting techniques, however, it is expected that this effect is limited around lift onset, where the peak moments occurred. It should be noted here that only low back and knee kinetics were studied. Initially, hip kinetics were included but these were highly correlated with low-back kinetics. However, upper extremity kinetics were not analysed and may have an effect on the MAWL.

4.3. Implications for practice

The results of this study are relevant in practice. Different tests of MAWL have been described in the literature (Bos *et al*. 2002) and are commonly applied to assess working capacity of individuals with LBP. This study supports the assumption that such lifting tests from knee to waist level and performed in a dynamic way reflect the loading of the low back, regardless of the lifting style used. This finding supports the assumption that MAWL, and more specific the psychophysical limits as used in the FCE assessment, are related to mechanical loading at the low back. These findings are in line with the conclusion of Fisher (2011), in his dissertation that for the upper extremity 'psychophysically acceptable forces are selected as a proportion of the maximum voluntary hand force, where the proportionality depends on the underlying biomechanical weakest link'.

Consequently, it is somewhat surprising that Schenk *et al*. (2006) did not find a stronger relation between maximum voluntary isometric strength trunk extensor strength and MAWL. Possibly maximum trunk strength measurements poorly reflect the ability to generate dynamic moments in lifting. This might also explain why Gouttebarge *et al*. (2009) found that future risk of work disability in construction workers on sick leave due to musculoskeletal complaints was poorly associated to isometric MAWL, and moderately correlated to dynamic MAWL and why especially dynamic lifting tests are predictive of work participation in patients with low back complaints (Kuijer *et al*. 2011). In addition, usually, tests of MAWL do not entail instructions on lifting technique. The present study showed that the relation between the load mass lifted and lumbosacral extension moment was dependent on the technique used. While the MAWL differed between techniques, the peak moments when lifting the MAWL was consistent across techniques. This implies that differences in MAWL between participants with the same trunk extensor strength may in part be accounted for by differences in lifting technique used as was suggested by Schenk *et al*. (2006). This also suggests that standardisation of lifting technique used in tests of the MAWL would be indicated if the aim is to assess the capacity of the low back. Moreover, this should preferably be done in a realistic simulation of the work situation (Faber *et al*. 2011).

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